Experimental Determination of the Ideal Gas Constant

Objectives

The objectives of this lab are to experimentally determine the value of the Gas Constant, R, and to practice using the Gas Laws to solve a variety of problems.

Background

A gas is the state of matter that is characterized by having neither a fixed shape nor a fixed volume. Gases exert pressure, are compressible, have low densities and diffuse rapidly when mixed with other gases. On a microscopic level, the molecules (or atoms) in a gas are separated by large distances and are in constant, random motion.

Four measurable properties can be used to describe a gas quantitatively: pressure (*P*), volume (*V*), temperature (*T*) and mole quantity (*n*). The relationships among these properties are summarized by the Gas Laws, as shown in the table below.

Charles's Law:	V α T [*P* and *n* are held Constant] As gas temperature increases, gas volume increases.	
Boyle's Law:	$V \propto \frac{1}{P}$ [*T* and *n* are held Constant] As gas pressure increases, gas volume decreases.	
Avogadro's Law:	V αT [*P* and *T* are held Constant] As the number of moles of gas increase, gas volume increases.	$\frac{n_1}{V_1} = \frac{n_2}{V_2}$
Combined Law:	$V \propto \frac{T}{P}$ [*n* are held Constant] Obtained by combining Boyle's Law and Charles's Law.	

Question 1: *Add the correct formulas for the gas laws above, try to do so from memory*

A closer look at the Combined Law reveals that the volume of a gas depends on both the pressure and temperature. Thus, if the volumes of two gases are to be compared, they must be under the same *P* and *T*. A commonly used set of *P* and *T* reference conditions is known as Standard Temperature and Pressure, or STP. Standard temperature is defined as exactly 0 °C (273 K) and standard pressure is defined as exactly 1 atm (760 mm Hg).

The Ideal Gas Law is obtained by combining Boyle's Law, Charles's Law and Avogadro's Law together:

$$PV = nRT$$

Here, *P* represents as the gas pressure (in atmospheres); *V* is the gas volume (in Liters); n is the number of moles of gas in the sample; *T* is the gas temperature. *R* is a proportionality constant called the Gas Constant, and has a theoretical value of 0.08206 $\frac{\text{L atm}}{\text{mol K}}$.

Question 2: *What unit should each variable in the ideal gas lab be in for this lab in order for R to cancel each of them out correctly?*

Pre lab:

Answer all of the embedded questions 1-9

Make a data table for all of the information you will need to collect in the procedures

In this lab, students will measure various properties of a sample of hydrogen gas in order to experimentally determine the value of the Gas Constant, R. The single displacement reaction between magnesium metal and hydrochloric acid will be used to generate the hydrogen gas:

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

The hydrogen gas will be collected in a eudiometer, a tube closed at one end and marked in milliliter volume units. The gas will be collected in the closed end of the tube over a water bath via the technique of water displacement (see figures 1).

Students will then obtain the following values for the collected sample of hydrogen gas: (1) Volume, (2) Temperature, (3) Moles, and (4) Pressure. The hydrogen volume will be directly measured from the eudiometer scale, with some minor adjustments. The hydrogen temperature will also be directly measured using a thermometer. However, the mole quantity and pressure of the hydrogen gas must be determined indirectly. The mole quantity of the collected hydrogen can be easily calculated from the measured mass of the magnesium reactant using stoichiometry. But the hydrogen pressure is a little more difficult to obtain. Since hydrogen is collected over a water bath, a small amount of water vapor is mixed with the hydrogen in the eudiometer. The combined pressure of the H_2 and H_2O gases will be equal to the total pressure. After adjustment (see "pressure equalization" in lab procedures) the total pressure will equal the external atmospheric pressure:

$$P_{atm} = P_{total} = P_{hydrogen} + P_{water\ vapor}$$

P_{atm} (atmospheric pressure) will be measured using a barometer, or QR code on last page of lab to link to local weather station at school.

$P_{water\ vapor}$ (the partial pressure of water vapor) depends on the temperature of the water bath, and can be obtained from the table supplied below. By substituting these values in the above equation, the pressure of hydrogen ($P_{hydrogen}$) will be determined.

Table 1

Temperature (°C)	P_{water} vapor (mmHg)
16	13.5
17	14.5
18	15.5
19	16.5
20	17.5
21	18.7
22	19.3
23	21.1
24	22.4
25	23.8
26	25.2
27	26.7
28	28.3
29	30.0

Question 3: *After reading through the lab, how will you determine or calculate the following for your experiment, be specific.*

P_{total} P_{atm} $P_{hydrogen}$ $P_{water\ vapor}$

Finally, to determine the value of the Gas Constant (*R*), the quantities *V*, *T*, *n* and *P* obtained for the hydrogen gas must simply be substituted into the Ideal Gas Equation. Students can then evaluate their accuracy in this experiment by comparing their experimental result to the true theoretical value of R, and by calculating their percent error.

Questions 4: *How will you calculate percent error for value of R you found in this lab?*

Safety
Concentrated HCl is dangerous!
Also note that hydrogen gas is flammable, so be sure to have no open flames nearby when you perform this experiment.

Materials and Equipment
4.0-cm ribbon of magnesium, length of copper wire (reusable), 6M HCl (*aq*), 50-mL eudiometer*, eudiometer stopper with hole(s)*, burette stand, large beaker, thermometer, small funnel, small graduated cylinder, barometer, large tub of water, electronic balance and steel wool

> **Question 5:** *a. If "6M" is the abbreviation for* $6\frac{mol}{L}$ *and you used 10mL of the 6M HCl, how many moles of HCl are in the solution?*
> *b. Using your moles of HCl you just calculated what mass of Mg would be needed to consume all of the HCl.*

Experimental Procedure
Magnesium Ribbon
1. Obtain a ~4.0-cm ribbon of magnesium (Mg) and a length of copper wire.

2. Carefully clean the outside of the Mg ribbon to remove any oxide coating with the steel wool. Do not sand on the bench top! Place the Mg ribbon on a paper towel while sanding. Weigh the cleaned Mg ribbon and record this mass on your report form. Note that this mass should be less than 0.04 grams. If it is heavier, your Mg ribbon will have to be "trimmed" by your instructor.

> **Question 6***: a. Knowing the mass of your Mg now, what is the limiting reagent in the reactions?*
> *b. What quantity of mole of* H_2 *could theoretically be produced?*

3. Wrap the Mg around the end of the copper wire. Do this in a tight ball with only a small gap between layers. Then wrap the copper wire to form a cage around the Mg ball. The cage must be tight enough to keep the Mg inside, but loose enough to allow water to easily flow around the wire. Roughly 3-cm of copper wire should be left over as a "handle" (see Figure 1).

Eudiometer Set Up and Reaction
4. Obtain a eudiometer tube (burret) and stopper (with holes) from the Mr. Golden. Use the burette clamp to hold it in place, open end up and spout closed.

> **Questions 7:** *a. What is the issue with using the burret for gas collection and measuring volume? (Hint look and the graduation marks)*
> *b. How can we account for and remedy this error?*

5. Add ~10-mL of 6M HCl (*aq*) to the eudiometer tube using a small funnel. Then add tap water to the eudiometer carefully until it is filled to the brim (see Figure 1).

6 . Hang the Mg ball inside the open end of the eudiometer, ~2-cm down from the top. Then insert the stopper into this end, and, while holding it in place, using a piece of plastic wrap on your finger quickly invert the entire tube into your largest beaker ¾ filled with water or the filled sink. Clamp the tube in the water in the upside down position (see Figure 2).

7. The reaction will occur as soon as the acid diffuses down the tube and reaches the Mg ribbon.. Allow the reaction to proceed until no Mg is left and no further gas is formed. This should take 3-5 minutes.

> **Questions 8:** *Once the reaction starts what gas is being produced and what process is removing the water from the tube (see Figure 2)?*

Figure 1

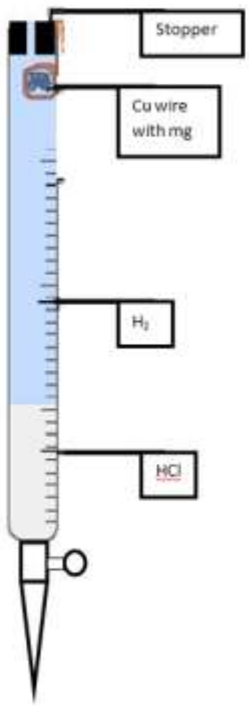
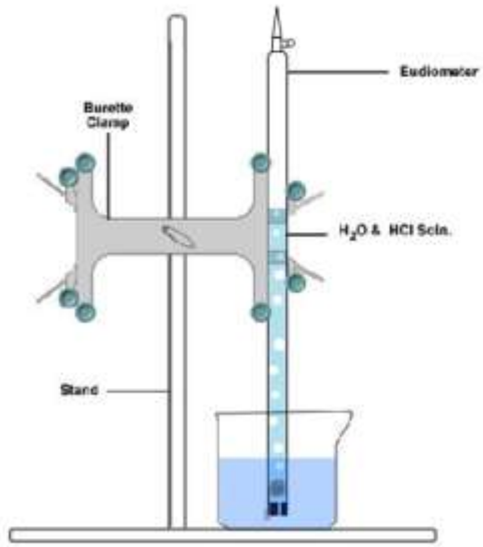


Figure 2



Pressure Equalization

8. To ensure that the pressure of hydrogen (and water vapor) in the eudiometer is equal to atmospheric pressure, the level of the water inside the tube must be the same as the level of water outside the tube.

> **Questions 9:** *How can you achieve this [equal pressure] once the reaction is over?*

Measurements

9. After equalizing the water levels, record the following measurements in your data table:

- The volume of hydrogen gas collected (read directly from the eudiometer scale), in mL
    Remember to account for the volume of the none graduate portion of the burret
- The temperature of the hydrogen gas collected, in °C. This can be measured by first removing the stopper then placing the thermometer directly in the eudiometer (keep the tube inverted so the gas does not readily escape). It is also acceptable to assume that the temperature of the hydrogen gas is the same as the temperature of the water bath, especially if you wait a while before making your measurements.
- The atmospheric pressure (use the lab barometer or QR web link), in mmHg
- The temperature of the water in the sink/ beaker/ bucket (use the thermometer), in °C
- The vapor pressure of water at the above temperature (obtain from Table 1), in mm Hg

10. When finished, repeat this entire procedure a second time with a fresh piece of magnesium ribbon.